

***DigitalBeing* – Using the Environment as an Expressive Medium for Dance**

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Abstract

Dancers express their feelings and moods through gestures and body movements. We seek to extend this mode of expression by dynamically and automatically adjusting music and lighting in the dance environment to reflect the dancer's arousal state. Our intention is to offer a space that performance artists can use as a creative tool that extends the grammar of dance. To enable the dynamic manipulation of lighting and music, the performance space will be augmented with several sensors: physiological sensors worn by a dancer to measure her arousal state, as well as pressure sensors installed in a floor mat to track the dancers' locations and movements. Data from these sensors will be passed to a three layered architecture. Layer 1 is composed of a sensor analysis system that analyzes and synthesizes physiological and pressure sensor signals. Layer 2 is composed of intelligent systems that adapt lighting and music to portray the dancer's arousal state. The intelligent on-stage lighting system dynamically adjusts on-stage lighting direction and color. The intelligent virtual lighting system dynamically adapts virtual lighting in the projected imagery. The intelligent music system dynamically and unobtrusively adjusts the music. Layer 3 translates the high-level adjustments made by the intelligent systems in layer 2 to appropriate lighting board, image rendering, and audio box commands. In this paper, we will describe this architecture in detail as well as the equipment and control systems used.

1. Introduction

Dance is an art of expression. When a dancer walks on stage, she captures the audiences' attention through her smooth and/or sharp movements and gestures reflecting her interpretation of the music in space. Dancers have been trained to use their bodies to express their inner feelings while improvising with music. Theatre dance extended the forms of dance expression by adding lighting and scenery. Similarly, we aim to extend the current forms of expression used in dance through the use of intelligent systems that adapt on-stage and projected lighting as well as music to reflect the dancer's arousal state measured through physiological sensors. The resulting artifact is the *DigitalBeing* – a personal signature of the dancer in digital space.

The *DigitalBeing* obtains its raw materials from a set of non-obtrusive and integrated physiological sensors embedded in an Ambient Intelligent dance environment. Ambient Intelligence (AmI) is a vision that integrates concepts ranging from ubiquitous computing to autonomous and intelligent systems to compose an environment where technology is invisible and embedded in everything around us acting autonomously on our behalf responding to our needs. In such environments (Vasilakos & Pedrycz, 2006) electronics will be integrated into clothing, furniture, cars, houses, offices, and public places. We seek to extend this vision to a dance space.

Dancers will wear wireless physiological sensors that measure three functions: 1) skin conductance, 2) cardiac activity, and 3) body temperature. In addition, we will install pressure sensors in the physical dance floor. The physiological data as well as pressure signals will be analyzed synthesizing the dancer's arousal state and identifying on-stage lights affecting the dancer, respectively. This information will then be distributed to three intelligent systems: an intelligent on-stage lighting system, an intelligent virtual lighting system, and an intelligent music system. The goal of both intelligent lighting systems is to express the dancers' arousal state through lighting color, angles, and layout. The intelligent on-stage lighting system

will adjust stage light colors, angles, and brightness given the arousal state. Similarly, the intelligent virtual lighting system will adjust colors, angles, and layout of lights within the virtual world projected on the backdrop. The intelligent music system will dynamically and unobtrusively adapt the music to the current dancer's arousal state. Artists will supply the music and virtual environment to be projected. Additionally, artists will also encode high-level directions indicating the style of lighting movement patterns and music changes.

We anticipate this kind of interaction to promote a method of self expression that allows dancers to use the entire environment as an expressive medium. We also anticipate that through the use of this interaction paradigm we can provide a new and original form of aesthetic experiences within a dance environment. We also hope that this kind of environment can promote dance as a form of self expression that can be used by ordinary people in interactive dance installations.

In this paper, we will discuss *DigitalBeing* in more detail. We will first briefly discuss dance as an art form to motivate our proposed vision. We will then discuss previous work in the area of interactive dance. We will follow with a detailed discussion of the proposed ambient intelligent system describing the sensors, the intelligent systems, and the utility of the system in extending the expressive potential of dancers within a dance space.

2. Previous Work

Our focus in this interdisciplinary project is to use technology to expand the current set of expressive methods in dance. This focus requires a study of dance, technology, and other performances that fused dance and technology. This section discusses these three dimensions; we start with a brief overview of the history of dance and its evolution as an art form. We follow with a discussion of the use of technology in dance performances; in particular, we discuss the use of technology in actual performances as well as academic research exploring the use of technology in dance spaces. The last section discusses Ambient Intelligence.

2.1 Dance

Dance as an art form appeared in the early Egyptian Civilization as a form of rituals used by hunters to find a prey. It then evolved into an art where professional performers danced at social events, and traveling groups danced in public squares of cities such as Thebes and Alexandria. In ancient Greece, dance was regarded as an important form of art that promotes physical health and education. During the Roman Empire, dance performances have been influenced with spectacle and mime. Through the years, dance has taken on different forms and shapes in different cultures. The emphasis, however, has always been the same: an expression of human emotions through body movements. Several dances took a free-form improvisational style; examples include African, Native American, Spanish, and Indian dances. Due to the prolific volume of dance forms that exist today and their variations, it is difficult to discuss all of them in this article. Thus, we will briefly outline some examples of free-form improvisational dances that have influenced our work.

There are several types of improvisational Indian dances. Most of these dances have evolved as deep religious activities. For example, Odissi dance is a dance used as a devotion to Lord Krishna. Odissi dancers use their heads, busts, and torsos in soft flowing movements to express specific moods and emotions. The Mohini attam is another form of dance used to show love and devotion to the god. In this form of dance, dancers use circular movements, delicate footsteps, and subtle expressions to express and suggest emotions.

Another form of dance that is primarily improvisational is the flamenco dance which evolved with influence from Indian and Middle Eastern dancing as well as tap dancing. Flamenco dancing is characterized with rhythmic hand movements, clapping, and tapping of the feet to express different emotions. In fact flamenco music itself consists of different beats that characterize a variety of human emotions. For example, the *Bulerias* is a form of flamenco that is festive and is used to celebrate life. In

contrast *Siguiriyas* is a form of flamenco music that is truly tragic expressing death, existential alienation, unrequited love, despair, desolation, and loneliness.

In addition to cultural dances, we have also looked at modern dance. Modern dance is a free-form improvisational dance developed in the early 20th century, when few dancers rebelled against the rigid constraints of classical Ballet and started practicing freeform dance. One of these dancers was Emile Jacques-Dalcroze who created a system of rhythmic gymnastics aimed at reaching a harmony between the static and dynamic forces of the human body. She believed in the creative richness of mixed media and choreographed pieces at the crossroad between dance and opera. Mary Wigman is another figure known for her influence in creating European Modern Dance in the late 1920s. In her dances, she focused on the expression of body movements that convey inner deep emotions. Decorations, costumes, and even music were unimportant in her dances.

Although we have not designed the proposed architecture for a specific dance form, the design lends itself well to improvisational free-form dance styles, such as the ones discussed above. For future work, we aim to evaluate the utility of the architecture in supporting and extending the expression of different dance forms, including flamenco dance (Spanish), belly dance, modern dance, Indian dance as well as other forms, such as African and Native American dances.

2.2 Dance and Technology

Numerous composers, choreographers, dancers, and theorists have explored the use of technology in theatre and dance. We do not intend to describe all the work that has been done in the realms of academic research, installations, or interactive productions here. However, we will discuss few examples that have influenced our work. Discussing these examples will situate our work, uncover its uniqueness, and its purpose.

One of the most influential and significant work that used animated figures for choreography is the work of Merce Cunningham. In his dance performance *Trackers*, he used a computer system called *Life Forms* devised by Tom Calvert (Calvert & Mah, 1996) to choreograph his dance movements. *Life Forms* is a piece of software designed to provide several stylized animated characters that allow users to create a dance choreography or explore certain steps. In addition to using animation for choreography, Cunningham also developed a virtual dance installation presented at Siggraph 1998 in collaboration with Paul Kaiser and Shelley Eshkar. This installation was composed of a mental landscape in which motion-captured hand-drawn figures performed intricate choreography in 3D (Cunningham, Kaiser, & Eshkar, 1998).

Besides the use of animated characters in a virtual performance, several performers have explored the use of animation within a real-life dance performance. For example, projected graphics have been used on backdrops in the San Francisco ballet *Pixellage* (Crow & Csuri, 1985). In one of the scenes they used a virtual animated ball (projected on the screen behind the dancers) which dancers threw to each other. Another ballet performance called *The Catherine Wheel* (Gruen, 1983) used an animated character to represent the spiritual figure of Saint Catherine. By using an animated character, artists can easily represent the spiritual nature of the character as opposed to using real life effects or make-up.

Another example of the mix between virtual and real characters is depicted in the work of Meador et al. (Meador, Rogers, O'Neal, Kurt, & Cunningham, 2004). They developed a collaborative production that mixes the use of virtual and real dancers within a dance stage. They used three different projectors within a dance performance; one of these projectors was used to project a virtual character that interacted with the dancers on stage (Meador et al., 2004). Their work was influenced by the work of Dan Saltz who directed *The Tempest* 2000 produced by the Interactive Performance Lab Group at University of Georgia [http://dpa.ntu.ac.uk/dpa_search/result.php3?Project=136]. In this production of *The Tempest*, they projected the character *Ariel* as a virtual character. They used motion capture to animate the character in real-time. The use of a synthetic character for *Ariel* added to his magical quality, and thus enhanced the overall performance.

Another example of the use of technology in dance performances is the use of motion capture to inform changes in projected imagery. Troika Ranch, a Dance Company situated in New York City [<http://www.troikaranch.org/>], developed a motion capture system called *MidiDancer*, which uses several cameras to capture performers' movements. They explored the use of the *MidiDancer* as a method of dynamically synthesizing dancer's movements and using these synthesized movements to dynamically alter the projected video during the performance. Even though they presented several unique and interesting ideas, the use of motion capture within dance productions is still an area under research and exploration.

Ulyate and Bianciardi showed their work on the Interactive Dance Club in Siggraph 1998 (Ulyate & Bianciardi, 1998, 2001). The interactive dance club was composed of several zones where they experimented with several setups and sensors, including infra-red, pressure, and vision. They divided the dance floor into different zones which induced different interactivity paradigms. For example, in one zone they had a set of parallel light beams that detected when beams were broken. By breaking beams of light, participants could trigger 4-16 notes of musical phrases.

Similar to the Interactive Dance Club, Todd Winkler explored the use of space, gesture, and motion capture equipment for music composition (Winkler, 1995, 1997, 1998). He focused on the use of dance and space to compose electronic music. He used the *Very Nervous System* (VNS) (Cooper, 1995; Rokeby, 1986, 1986-1990) which is a system composed of one or two cameras that detect speed and location of dancers. He explored several methods of mapping the output data from VNS to music parameters, such as frequency, pitch, timber, etc. (Winkler, 1997). He presented two productions in the late 1998 showing his work (Winkler, 1998).

Several artists have explored the reversal problem, how to visualize music in a 2D or 3D projection used in a dance performance. Currently WinAmp and Windows Media Player both include built in algorithms that map music into 2D space using a frequency spectrum extracted from the music file (*WinAmp*, ; *Windows Media Player*). Wagner and Carroll developed a 3D music visualization system called *DeepWave* (Wagner & Carroll, 2001). *DeepWave* analyzes music files extracting frequency, pitch, vocals, etc. and maps them to shape, color, texture, and animations in 3D space. Through experimentation they found that vocals are best mapped to color and transparency, percussion to size and shape, and guitars and keyboards to animation. *DeepWave* also allows users to author skins and input 3D scenes and textures.

Beyond projection as a way to influence the dance space, Louis-Philippe Demers have explored the utility of adjusting physical stage lighting within an art installation (Demers, 1993; Demers & Jean, 1997). He developed a system that uses several sensors including, pas sensors, video sensors, optical and infrared sensors, sonar sensors, and 3D ultrasound devices to predict blocking and gather gesture information. Using these as input, he developed a system that manipulated on-stage lighting in terms of light brightness, color, and angle. He showed this system in several projects, including *The Shadow Project* (Crawford, Schiphorst, Gotfritt, & Demers, 1993) and *Lost Referential* (Demers & Vorn, 1998). Our work will borrow and extend his technique by enabling change in light direction, color, and intensity based on dancer's arousal state; we will also base lighting manipulation on results of a qualitative study of film lighting patterns, which will be discussed in detail in section 3.4.1.

2.3 Ambient Intelligence (AmI)

Ambient Intelligence (AmI) integrates concepts ranging from ubiquitous computing to Artificial Intelligence (AI). AmI is the vision that technology will become invisible, embedded in our natural surroundings, present whenever we need it, attuned to all our senses, adaptive to users and context and autonomously acting. In an Ambient Intelligent environment (Vasilakos & Pedrycz, 2006), people are surrounded with networks of embedded intelligent devices that can sense their state, anticipate their needs, and perhaps adapt to these needs. This vision is quite different from contemporary handheld or stationary electronic boxes and devices. It includes the environment in which the users reside. This introduces the problem of developing user interfaces that allow users to interact with the environment seamlessly and naturally.

In this paper we aim to address the design of an ambient intelligent dance environment. There are several challenges to adapting the vision of ambient intelligence to a dance performance. First, dance environments require efficient real-time responses with little or no delay. Second, the dancer's contribution to the environment should be obvious enough that the dancers and audience members can acknowledge the effect consciously or subconsciously, yet it cannot be obtrusive as to destruct the dance experience.

We also acknowledge, as discussed by many dancers, that the technology should be used to enhance the aesthetic experience and not for its own sake. Therefore, the use of any technology within a dance space should be evaluated to identify its aesthetic value considering the experience of the dancer and/or audience. Testing and evaluating this particular environment is important. However, this kind of evaluation requires a complete working system, and thus will be addressed in future work.

3. Basic System

3.1 Space

We envision a space similar to a proscenium theatre stage. Stage lights will be rigged on posts. We will use a backdrop to project a virtual world developed by an artist for the dance performance. We will implant pressure sensors in the dance floor to track dancers' positions and movements. We will also include a 3D surround sound system to play the music composed for the performance. The dancer will wear an armband that collects physiological information while she freely moves around in the space. Sensor information will be transmitted wirelessly through a local network to a computer that then analyzes these information and alters the music, on-stage lighting, as well as the projected 3D world in terms of its lighting to express the dancer's arousal state.

3.2 Physical Equipment and Software used

3.2.1. Sound

We will use EVID premium surface mount speaker system 3.2 or better. We will also use an Audio Box designed by Richmond Sound Design [<http://www.richmondsounddesign.com/>] which allows for E-show control. This box will allow us to upload wav files and manipulate audio files through midi commands to shift pitch or adjust frequency. Additionally, we will use the Audio Box to shift between wav files to manipulate the music as a reflection of the dance's arousal state.

3.2.2. On Stage Lighting

According to our requirements, we need physical lights that accept commands to rotate in 3D space and change color dynamically during the performance. There are several types of intelligent dynamic light models developed for stage productions. We will use the *Mac700* light model depicted in figure 1. This light model can be programmed to dynamically rotate in 3D space; it also includes a color wheel that can upload up to 20 color gels. Therefore, during a performance, the lights can be programmed to shift between 20 predetermined color values. None of the current intelligent dynamic light models enable dynamic mixing of colors to produce smooth color changes as in a virtual environment. Therefore, preparation and planning is needed at the pre-production stage.



Figure 1. Mac 700 Intelligent Light Model developed by Martin Company
[\[http://www.martin.com/product/product.asp?product=mac700profile\]](http://www.martin.com/product/product.asp?product=mac700profile)

3.2.3. Physiological Sensors

Dancers will wear the SenseWear® PRO₂ Armband [<http://www.bodymedia.com/technology/index.jsp>], which is a wearable body monitor that enables continuous collection of low-level physiological data, including heat flux, skin temperature, near body temperature, and galvanic skin response. It also includes a streaming program that we will use to continuously and wirelessly stream the physiological data to a PC for processing while dancers freely move in space.

It, however, does not include a heart rate monitor. For that purpose, we will use the Triax Elite, which is composed of a stopwatch and a heart rate monitor strap that displays heart rate, current running pace, and pace target information for interval training. Like the armband, it also transmits heart rate data wirelessly. Since the rate of transmission of the heart rate device is different than that of the SenseWear device, we will build custom software to fuse the information collected from these sensors.

The choice of these particular devices was made due to our experience with them. After experimentation with several devices, we found that these two are particularly reliable when participants are engaged in athletic activities. Due to our previous research predicting emotional and arousal states, we believe that using both of these devices can give us a clear indication of the dancer's arousal state but not emotional state. Predicting emotional states is unfeasible using physiological sensors alone, additional information is required, such as postures, gestures, and facial expressions extracted through high resolution cameras. In this phase, our goal is to extract and identify dancer's arousal state rather than emotional state, and thus the two devices discussed above will suffice for our purposes.

3.2.4. Pressure Sensor Mat

We will adopt the floor mat design developed by Srinivasan et al. (Srinivasan, Birchfield, Qian, & Kidane, 2005); the mat is constructed of several light-weight high resolution pressure sensor mats. We will use between 20,800 and 100,000 sensors depending on the size of the dance floor. The sensors will be clustered together. Signals from these sensors will be sent directly to a host computer that assembles and identifies light IDs for lights on the stage affecting the dancer.

The pressure sensor floor mat designed by Srinivasan et al. (Srinivasan et al., 2005) is also capable of gathering other information, such as dancers' movements, gait, and foot gestures. As a first step, we aim to collect information on dancers' locations only. For future work, we plan to use the other information supplied by the pressure system to extend the current system.

3.2.5. Content and Artistic plan

As with any performance, artistic content is important. Artistic content for this particular piece include: the virtual 3D environment, and the music piece composed for the performance. In addition, artists will also control the stylistic parameters for lighting and music adjustments. For this purpose, all the proposed

intelligent systems will include tools that allow artists to input stylistic constraints to direct the lighting and music changes. To accomplish this goal, we will build several tools that allow artists to encode their input and content.

As mentioned above, artists will supply the system with the virtual world that will be projected on the backdrop. We will use Ogre 3D for rendering the virtual world. Ogre 3D is an open source rendering engine that is publicly available. It already includes several tools to allow artists to import 3D models of actors and environments from any 3D modeling software, such as 3D Studio Max or Maya, two most widely used software for building virtual worlds. We will augment these tools with an interface that allows artists to type in the file names for the 3D environments and models they want to use. The system will then automatically upload the appropriate environment and models.

Artists will also supply the system with the music to play for the performance. Since the system will dynamically adjust the music to reflect dancer's arousal state, artists will need to compose the music piece in several segments, e.g. piece1, piece2, piece3, etc. Artists will also compose transitions from one piece to the other, e.g. transition1 transitions from piece1 to piece2, etc. The system requires artists to encode these pieces as wav files. Artists will provide the system an XML file declaring the name of the segment and the corresponding wav file, e.g.:

```
<Music Piece>
  <Name> Piece1 </Name>
  <FileName> piece1.wav </FileName>
</Music Piece>
```

And another XML file defining the transitions, e.g.:

```
<Transition>
  <Name> Trans1 </Name>
  <FileName> trans1.wav </FileName>
  <From> Piece1 </From>
  <To> Piece2 </To>
</Transition>
```

In addition, artists will encode how the pieces follow each other. For this purpose, we will develop a rule-based authoring tool that artists can use to direct the music piece selection algorithm (part of the intelligent music system). This authoring system as well as the intelligent music system will be discussed in section 3.5.

There are several stylistic parameters to govern the lighting design and lighting changes through time. The intelligent lighting systems, described later, allow artists to supply several numerical values that control: (1) the lighting design, and (2) lighting movement patterns through time. These constraints or parameters will be identified as we discuss the intelligent lighting systems in section 3.4.

3.3 Architecture

The architecture is composed of several subsystems (shown in figure 2). The *Sensor Analysis System* analyzes two sensor signals: physiological sensor signals formulating the dancer's arousal state, and pressure sensor signals identifying lights relevant to dancer's positions. The arousal state will be stored in a structure called *Dancer Arousal State* represented in XML. The lights relevant to dancer's positions will be stored as a list of light IDs that are continuously changing as the dancer moves.

The *Dancer Arousal State* structure will be passed to three systems: *Intelligent Virtual Lighting System*, *Intelligent on-stage Lighting System*, and *Intelligent Music System*. The intelligent Music System will manipulate the music by dynamically substituting authored music segments and transitions based on the dancer's arousal level and authored rules. Both lighting systems are based on the work of Seif El-Nasr on Expressive Lighting Engine (ELE) (Seif El-Nasr, 2005; Seif El-Nasr & Horswill, 2004). The *Intelligent Virtual Lighting System* uses virtual space info of the 3D environment model provided by the artist, artistic constraints, as well as the *Dancer Arousal State* to compute a light setup, if none exists. A light setup consists of the number of lights to use in the virtual environment and their placements. Once a light setup is calculated, the *intelligent virtual lighting system* determines colors and angles for each light specified in the light setup. These values will be calculated based on the dancer's arousal state using theatre and film

lighting design theory (Alton, 1995; Birn, 2000; Block, 2001; Gillette, 1998), as will be discussed below. The light setup, colors, and angles will be given to a game engine to render the frame, which is then projected on the cyclorama.

Similarly, the *intelligent on-stage lighting system* determines colors and angles for stage lights given the light IDs of lights affecting the dancer, the dancer's arousal state, and artistic constraints dictating stylistic lighting parameters. It, however, determines color based on color gels specified in its database (which contains all gels uploaded by artist in preproduction and their color wheel location). It also does not generate a light setup. Instead, it categories lights on stage as: focus lights which are lights affecting dancers given by the list of light IDs (output of Sensor Analysis System), and non-focus lights, all lights not in the list of light IDs. Based on this difference, it identifies, for each physical on-stage light, a color from the color wheel and an angle rotation. This information is then translated to light board hex code by the *On-stage Lighting Trans System*.

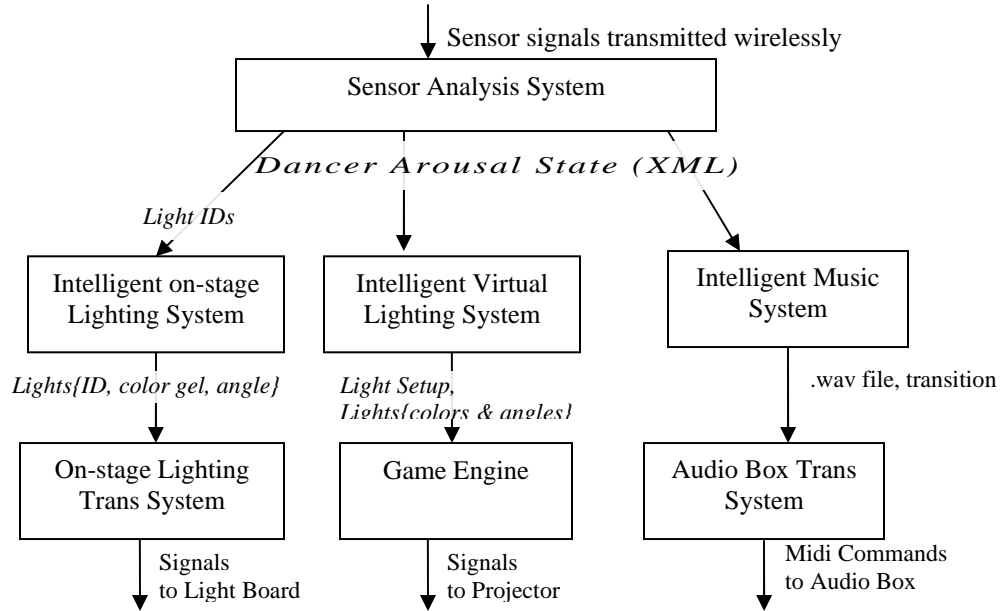


Figure 2. Architecture of the System

3.3 Sensor Analysis System

3.3.1. Reading and Interpreting Arousal

Using the physiological sensors discussed in section 3.2.3, we will collect GSR (Galvanic Skin Response), heart rate, and body temperature. These signals are continuous numerical values. We will pass these signals through a filter and will synchronize their readings and sampling rates. The output of this system is a continuous function describing arousal in time increments, where the sampling rate will be the *max* of all sampling rates of the used sensors.

3.3.2. Gathering Blocking Information through Pressure Sensors

Gathering blocking information is important to allow more intelligent lighting changes and setup, e.g. composing lights to focus on the dancer. At preproduction, we will manually map lights to specific mat numbers. Receiving pressure signals from a specific mat will indicate a person stepping on the mat. Therefore, instead of gathering or mapping 3D positions, we will pass dancer position as a mat number(s). Using the lights-to-mat mapping, we will determine which lights will impact the dancer at any particular moment in time. The output of this system is a list of light IDs of lights affecting the dancer at the specific moment in time. We anticipate this particular output to be continuously changing. Therefore, output from

this system will be buffered and fed to the next layer for processing as a process within the next layer becomes available.

3.4 Expressing Arousal through Lighting

3.4.1. *Lighting Patterns for expressing arousal – Based on Film and Theatre Lighting Theory*

Films and theatre productions use several color and lighting techniques to parallel and support the dramatic intensity expressed in the narrative (Birn, 2000; Block, 2001; Bordwell & Thompson, 2001; Brown, 1996; Calahan, 1996; Cheshire & Knopf, 1979; Crowther, 1989; Gillette, 1998). The specific effects or colors used for expressing emotions vary. For example, some shows use warm colors to signify positive emotions and cool colors to signify negative emotions; other shows use an opposite pattern. We believe that the actual link between emotions and color is ambiguous and may vary with culture.

In this section, we will concentrate on discussing several contrast and affinity patterns that are used to evoke or parallel tension¹ (Almeida, 2005). We formulated these patterns based on a qualitative study of over thirty movies, including *The Cook, The Thief, His Wife and Her Lover*, *Equilibrium*, *Shakespeare in Love*, *Citizen Kane*, and *The Matrix*. According to our study, the techniques used can be divided into shot-based color techniques: color techniques used in one shot, and scene-based color techniques: techniques used on a sequence of shots.

An example shot-based color technique is the use of high brightness contrast in one shot. Brightness contrast is a term we use to denote the difference between brightness of different areas in the scene. High brightness contrast denotes high difference between brightness in one or two areas in a shot and the rest of the shot. This effect is not new; it was used in paintings during the Baroque era and was termed *Chiaroscuro* which is an Italian word meaning light and dark. An example composition can be seen in Giovanni Baglione's painting *Sacred love versus profane love* shown in figure 3. This kind of composition is used in many movies to increase arousal. Perhaps the most well known examples of movies that use this kind of effect are film noir movies (shown in figure 4), e.g. *Citizen Kane*, *The Shanghai Gesture*, *This Gun For Hire*. Another form of contrast used in movies is the contrast between warm and cool colors (Block, 2001). An example shot appeared in *The Shinning* used a high warm/cool color contrast composition, where contrast is defined as the difference between warm colored lights lighting the character and cool colored lights lighting the background. These kinds of patterns are usually used in peak moments in a movie, such as turning points. Lower contrast compositions often precede these heightened shots, thus developing another form of contrast, contrast between shots.



Figure 3. Chiaroscuro Technique used in *Sacred love versus profane love* Painting

¹ This work is partly my student's master's work at Penn State University done in collaboration with the first author, Professor Seif El-Nasr.



Figure 4. Film Noir uses contrasts and shadows

In addition to color and brightness contrast, filmmakers also used affinity of color, e.g. affinity of high saturated warm colors or unsaturated cold colors in one shot (Birn, 2000; Block, 2001; Bordwell & Thompson, 2001; Brown, 1996; Calahan, 1996; Cheshire & Knopf, 1979; Crowther, 1989; Gillette, 1998). An example movie that extensively used this technique is *The Cook, the thief, his wife, and her lover*. Other examples include *The English Patient*, which used affinity of de-saturated colors, and *Equilibrium*, which used affinity of cold unsaturated colors.

The perception of contrast, saturation, and warmth of color of any shot within a continuous movie depends on colors used in the preceding shots. Also, the process by which color is used to evoke or project dramatic intensity depend on the sequence and temporal ordering of the effects discussed above. For this purpose, we define our patterns in terms of techniques spanning time over several shots.

The first technique we discuss is the use of affinity of saturated colors for a period of time. Movies, such as *The Cook, the thief, his wife, and her lover*, sustained affinity of highly saturated warm colors for a period of time. We believe that the temporal factor is key to the effect of this approach; this is due to the nature of the eye. The eye tries to balance the projected color to achieve white color. Hence, when projected with red color, the eye will try to compensate the red with cyan to achieve white color. This causes eye fatigue, which in turn affects the participant's stress level, thus affecting arousal.

Based on this observation, we identify the following pattern:

Pattern I: Subjecting audience to affinity of high saturated colors (where high saturation ranges from 70% to 100%) for some time increases arousal

In contrast to the use of affinity, several movies used contrast between shots to evoke arousal (Alton, 1995; Block, 2001). For instance, filmmakers used warm saturated colors in one shot then cool saturated colors in the other, thus forming a warm/cool color contrast between shots to reflect a decrease in dramatic intensity. Some designers use saturated colored shots then de-saturated colored shots creating a contrast in terms of saturation; example films that used this technique include *Equilibrium* and *The English Patient*.

Based on these observations, we identify the following patterns:

Pattern II: Subjecting audience to contrast in terms of high saturated then low saturated colors (where saturation ranges from 100% to 10%) over a sequence of shots decrease arousal

Pattern III: Subjecting audience to contrast in terms of low saturated then high saturated colors (where saturation ranges from 10% to 100%) over a sequence of shots increase arousal

Pattern IV: Subjecting audience to contrast in terms of high brightness then low brightness (where brightness ranges from 100% to 10%) over a sequence of shots increase arousal

Pattern V: Subjecting audience to contrast in terms of low brightness then high brightness (where brightness ranges from 10% to 100%) over a sequence of shots decrease arousal

Pattern VI: Subjecting audience to contrast in terms of warmth then cool colors (where warmth ranges from 100% to 10%) over a sequence of shots decrease arousal

Pattern VII: Subjecting audience to contrast in terms of cool then warm colors (where warmth ranges from 10% to 100%) over a sequence of shots increase arousal

Pattern VIII: Subjecting audience to increase of brightness contrast subjected in a shot (where brightness contrast is measured in terms of difference between bright and dark spots in an image) over a sequence of shots increases arousal

Pattern IX: Subjecting audience to decrease of brightness contrast subjected in a shot (where brightness contrast is measured in terms of difference between bright and dark spots in an image) over a sequence of shots decrease arousal

Pattern X: Subjecting audience to increase of warmth/cool color contrast subjected in a shot (where contrast is measured in terms of difference between warm and cool spots in an image) over a sequence of shots increases arousal

Pattern XI: Subjecting audience to decrease of warmth/cool color contrast subjected in a shot (where contrast is measured in terms of difference between warm and cool spots in an image) over a sequence of shots decreases arousal

These patterns will be used by the intelligent lighting system to manipulate lighting in real-time to reflect a decrease or an increase in dancer's arousal state based on the current lighting state as will be discussed below.

3.4.2. Intelligent Virtual Lighting System – Dynamically Manipulating virtual lights to express Arousal

This system is based on Seif El-Nasr's work on ELE (Expressive Lighting Engine) (Seif El-Nasr, 2005; Seif El-Nasr & Horswill, 2004). The *intelligent virtual lighting system* extends ELE to include a temporal modulation of lighting based on the patterns discussed above. Before I discuss the intelligent virtual lighting system, I will briefly discuss ELE.

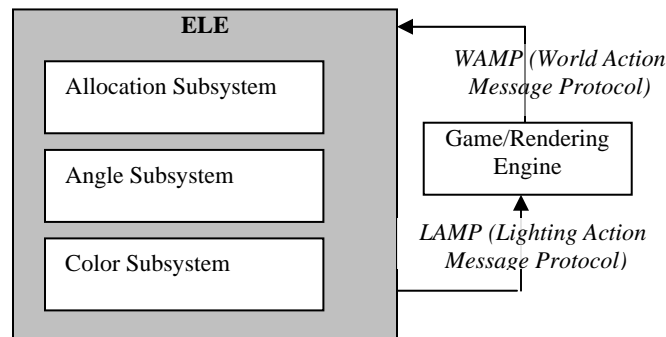


Figure 5. ELE's Architecture

ELE, Expressive Lighting Engine, is an automatic intelligent lighting control system developed based on cinematic and theatrical lighting design theories; it is designed to automatically select the number of lights, their positions, colors, and angles. To accomplish this task, ELE uses lighting design rules formulated based on a study of film and theatre lighting design techniques. These rules are represented mathematically in an optimization function. The use of optimization is important to balance conflicting lighting-design goals. While adjusting the lighting, ELE also maintains stylistic and artistic constraints.

ELE as a black box is illustrated in Figure 5. As shown, ELE takes in several parameters, represented as an XML structure called WAMP. These parameters are as follows:

- Stage layout or scene graph
- Locations of characters
- Local props that emit light, e.g. windows, torches, lamps
- Stylistic parameters including: low-key/high-key, desired depth value and importance or depth, desired direction, overall contrast level, overall palette, specific ideal saturation, warmth, intensity or hue values for particular areas in the level or scene
- Dramatic intensity of the scene

ELE then emits an XML-based structure called LAMP, which includes the following:

- Number of lights to be used.
- For each of these lights:
 - type of instrument (e.g., spot light or point light)
 - color in RGB color space
 - attenuation
 - position as a 3D point
 - orientation including the facing and up vectors
 - range
 - masking parameters
 - Depending on the light instrument used, the Penumbra and Umbra angles.

These parameters are given to a rendering engine to render the frame.

Using theatrical and cinematic lighting design theories, ELE uses stage layout or scene graph information as well as artistic stylistic constraints to device a light layout. It divides the scene into n different cylindrical areas. It then categorizes these areas as: focus, describes the focus of the scene, non-focus, areas surrounding the focus area, and background areas. This is important because a lighting designer often uses light to bring out the focus, increase depth by varying brightness or color of lights in different areas, or increase contrast (determined by colors of lights lighting focus and non-focus areas). ELE determines where to direct viewers' attention (or the focus) given the number of characters in the frame and the dramatic importance of their actions. Artists can manipulate the style of lighting by adjusting several constraints, which include desired values for depth, motivation, contrast, etc., and their importance. Using these constraints, ELE determines the number of lights to use, their locations, and angles.

The interaction between colors assigned for each area in a scene composes the contrast and feeling of the entire image. Thus, we differentiate between the three types of areas: background, focus, and non-focus. We calculate contrast and depth according to the difference between colors assigned to each area. Using the supplied lighting constraints, ELE uses constrained nonlinear optimization to select an appropriate color for each individual light in the scene to balance these constraints.

The *intelligent virtual lighting system* will generate light layout and angles using the angle and allocation subsystems defined in ELE. It will extend ELE's color subsystem to allow selection of colors based on the patterns discussed in 3.4.1. These patterns can be summarized as follows:

1. Arousal increase/decrease can be mapped linearly to brightness contrast increase/decrease, where contrast is established between focus and non-focus areas, i.e. difference in brightness between colors of lights lighting focus areas and others lighting non-focus areas.
2. Arousal increase/decrease can be mapped linearly to warm/cool color contrast increase/decrease, where contrast is established between focus and non-focus areas, i.e. difference in warm and cool colors of lights lighting focus areas and others lighting non-focus areas.
3. Arousal increase/decrease can be mapped linearly to saturation affinity increase/decrease, where brightness and hue is constant.
4. Arousal increase/decrease can be mapped linearly to warmth affinity increase/decrease, where brightness and hue is constant.

Depending on artistic input indicating which pattern or style he/she desires, the intelligent virtual lighting system will adjust light colors based on the selected pattern.

The output of this system is a light setup, if one did not exist. The light setup consists of the number of lights and their layout. In addition, the system also determines angles and colors for each light in the light setup. This information is continuously changing as the dancer moves or his/her arousal state changes. These continuously changing parameters will be passed to the rendering engine.

3.4.3. Intelligent On-Stage Lighting System – Dynamically Manipulating on-stage lights to express Arousal

Manipulating on-stage lighting is less fluid than virtual lighting. Continuous changes can only be made to brightness through the use of dimmers and to angle through rotation of the lighting devices. Continuous

control of color is not feasible with the color wheel design of the dynamic stage light models currently available. In other words, color changes can no longer be made in term of fluid changes in RGB color space as is the output of ELE. The color wheel contains twenty slots where artists can install different color gels. Therefore, color changes will be predefined and made on certain cues or at specific thresholds. The intelligent on-stage lighting system stores for each physical light, a list of RGB and HSB (Hue Saturation, and Brightness) values for the colors installed on the color wheels. In addition, it also stores the light setup which consists of the rigged lights and their IDs.

The *intelligent on-stage lighting system* reuses several components from the *intelligent virtual lighting system*, particularly the color and angle systems. Given the light IDs of lights affecting the dancer (the output of the sensor analysis system), the *intelligent on-stage lighting system* computes angles of each light affecting the dancer using the same angle sub-system used in the *intelligent virtual lighting system*. The other lights on the stage are set to a default angle that creates a wash on the stage.

Reusing the color subsystem, the intelligent on-stage lighting system computes RGB color values of each light category based on the patterns discussed above and the dancer's arousal state. The *intelligent on-stage lighting system* categorizes lights affecting the dancer as focus lights and other lights as non-focus lights. Given this categorization, the RGB color values, and the list of lights and their color gels, we will use the kth-nearest neighbor algorithm to find the best match color value given the color gels installed. Distance will be measured as the difference between the RGB colors of both the desired RGB color and the RGB color of the color gel.

3.5 Expressing Arousal through Music

Expressing arousal in music is difficult. Since our emphasis is on lighting, we will develop a simple system for improvising music; the system is similar to the work on adaptive music done by the game industry (Clark, 2001; Miller, 1997; Patterson, 2001; Ross, 2001). The basic idea is that composers will compose the improvisational piece as a set of several pieces that can be interchangeable and that vary in their projected tension level. For example, composers will supply us with: piece1 which can be replaced with piece11 piece12, piece13, etc. where piece11, piece12, piece13 show different tension levels depending on the pattern or pieces already played. Artists will use XML to identify the pieces, as follows:

```
<Music Piece>
  <Name> Piece1 </Name>
  <FileName> piece1.wav </FileName>
</Music Piece>
<Music Piece>
  <Name> Piece11 </Name>
  <FileName> piece11.wav </FileName>
</Music Piece>
<Music Piece>
  <Name> Piece12 </Name>
  <FileName> piece12.wav </FileName>
</Music Piece>
<Music Piece>
  <Name> Piece13 </Name>
  <FileName> piece13.wav </FileName>
</Music Piece>
```

They will then use rules to denote the tension value of pieces given specific patterns, e.g.

```
IF      (played piece1)
        and (played piece2)
        and (played piece3)
        and (istobeplayed piece14)
where   (followed-directly piece2 piece1)
Then    tension value is increased by 10
```

Where *played* is a symbolic predicate representing the fact that piece1 was played. This particular fact is placed in the rule-base database when piece1 is selected for playing and is played. The *where* part of the rule indicates some specific temporal or transitional constraints, such as followed-directly, which indicates

some piece followed another piece directly, e.g. piece2 followed piece1 directly. The rule above denotes that if the piece14 is played after piece3, piece2, and piece1, and piece2 followed piece1 directly then the tension value would increase by 10 increments. Using these rules the *intelligent music system* will evaluate several candidate pieces given the increase/decrease of tension values and the *Dancer Arousal State* value read by the *Sensor Analysis System*. For example, if the arousal state dictates an increase of 5-7 increments in dancer's arousal then a closer increase to 5-7 increments would be the best match. The intelligent music system will evaluate all candidate pieces in terms of their tension value increase and will select an increase that is closer to the dancer's arousal state increase. If there are several appropriate candidates, then the system will choose one randomly. The system will select transitions in a similar manner.

In order for the intelligent music system to select a candidate piece given the authored pieces, it will use a rule-based system similar to the one discussed in (Forbus, 1993). Again, artists will author several rules indicating when a particular piece becomes applicable for playing. For example, piece14 can be selected only if piece1 and piece2 have been played, this can be expressed as:

```
IF          (played piece1)
            and (played piece2)
Then       put piece14 in candidate list
```

The intelligent music system will then put piece14 in the candidate list if piece1 and piece2 have been played at some point in the past. The system then selects a piece to play from the candidate list by comparing their increase/decrease of tension value using the rules above. When a piece is selected to play, then the fact (play ?piece), where ?piece is the piece that has been selected, will be placed in the fact database.

3.6 Projecting Lighting and Music

3.6.1. Game Engine

In this project, we will use an open source rendering engine called Ogre 3D, which has been used to render intricate 3D environments in real-time. It also includes an SDK (Software Development Kit) that designers can use to dynamically manipulate 3D objects, such as lighting, characters, and camera. To dynamically manipulate lighting using this engine, we will build an interface library that translates *intelligent virtual lighting system* lighting commands to specific game engine methods.

3.6.2. On-Stage Lighting Trans System

The output of the intelligent on-stage lighting system is: a list of light IDs, and for each light ID, an angle and a color gel location. This output is passed to the *On-stage Lighting Trans system* which translates these commands to appropriate hex code commands used by the lighting board. The hex code will include routines to initiate light rotation or color wheel rotation commands for the appropriate lights given the output of the intelligent on-stage lighting system.

3.6.3. Projecting Music

As described above, the intelligent music system determines which wav files to play. Commands for switching between wav files will be sent to the audio box, which can dynamically switch between wav files. We assume all segments will use cross fade as a transition method. Cross fade is a method of transitioning between two music pieces where one is faded out and the other is faded in.

4. Discussion

We have described an ambient intelligent environment for a dance space. Our goal is to extend the current expression modes of dance by allowing lights and projected images to change and adapt depending on dancer's movements and arousal state. By changing lighting color, direction, and lightness directly mapping the dancer's condition, we are presenting the dancer's state as a signature within the actual space. Such an interface will also allow dancers to use the environment as their expressive space and to project their own self through the environment.

We have intentionally limited the technical design to only adapt to arousal state and not emotional state. This is due to the fact that extracting or predicting emotions is still a hard and open problem. It is especially problematic because most often dancers feel an amalgam of emotions and not one particular emotion. One possible way to predict emotional states is to use a high resolution image processing algorithms to analyze facial expressions and gestures. These techniques are still under research and are generally challenged by variation in lighting conditions. Therefore using them for this project is problematic. In addition, the lighting patterns we extracted from film techniques use light and color primarily to project tension rather than actual emotions. Hence, even if we can devise a method for predicting emotional states, defining lighting design patterns that can universally represent emotional states is difficult.

While few interactive theatre productions used vision to capture on-stage motion, we decided to use pressure sensors. This decision was made for several reasons. First, most vision techniques are challenged by variations in the level of illumination within the captured images. This is due to the fact that most vision techniques use pixel colors to define edges and track movement. Since we propose a performance where lighting color and angle change dynamically to reflect the arousal state of the dancers, this environment, by definition, will constitute a challenge to any vision based system. Second, privacy of dancers may be an issue for our piece. Third, we need to establish a mapping between dancers' positions and lights on stage. While we could use vision techniques to track movements, determining 3D position and its relation to lights on stage is hard.

This work has several applications beyond dance performances. We envision that this work can extend and augment current work on the use of music and dance for health therapy (Aktas & Ogce, 2005; Flores, 1995; Jeong et al., 2005; Noreau, Martineau, Roy, & Belzile, 1995). In addition, by developing a more adaptive dance space, we can promote a better sense of engagement and immersiveness within dance spaces. This may lead to adoption of the technology and dance among ordinary people.

5. Conclusion

In this paper, we have discussed a new ambient intelligent environment that expresses a dancer's arousal state through manipulation of music and stage lighting as well as lighting of a virtual world projected around the dancers. The contribution of the paper is in the architecture presented which describes an ambient intelligent environment composed of several intelligent systems. First, a sensor analysis system analyzes physiological sensor data as well as identifies lights on the stage that affect the dancer (at any given moment in time) given pressure sensor readings. Second, two intelligent lighting systems initiate stylistic expressive manipulation of on-stage and projected lighting over time reflecting the dancer's arousal state. Last, an intelligent music system adapts the music based on the dancer's arousal state. The goal of the described architecture is to enable different modes of expression through a dance space, and provide a method that imprints a signature of the dancers' self in the physical dance space. In creating this signature, we seek to allow people to experience their own *DigitalBeing* and bring performance art to the people, while also offering to performance artists a creative tool to extend the grammar of the traditional theater dance. In future work, we aim to implement this architecture and evaluate its aesthetic utility within different dance forms, including Indian dance, modern dance, and flamenco dance.

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